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RESEARCH PAPER

Quality assessment in seven different apple varieties commercialized in Portugal

Tomislava Živić[1], Ana Rita F. Coelho[2,3], Ana Coelho Marques[2,3], Diana Daccak[2,3], Inês Carmo Luís[2,3], Cláudia Campos Pessoa[2,3], Fernando Lidon[2,3], Maria Manuela Silva[2,3], Manuela Simões[2,3], Paulo Legoinha[2,3], Fernando Henrique Reboredo[2,3]

1 *Josip Juraj Strossmayer University of Osijek, Trg Svetog Trojstva 3, 31000 Osijek, Croatia*

2 *Departamento Ciências da Terra, Faculdade de Ciências e Tecnologia, Universidade NOVA de Lisboa, Campus da Caparica, 2829-516 Caparica, Portugal*

3 *Unidade de Geobiociências, Geoengenharias e Geotecnologias (GeoBioTec), Faculdade de Ciências e Tecnologia, Universidade NOVA de Lisboa, Campus da Caparica, 2829-516 Caparica, Portugal*

Corresponding author: Ana Rita F. Coelho (arf.coelho@fct.unl.pt)

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Abstract

Seven commercially available apples varieties in Portugal (Jongold, Pink Lady, Reineta, Fuji, Gala, Golden and Granny) were analyzed for their physical and chemical properties. In this context, mineral content, height, weight, diameter, firmness, total solids soluble content, color, total lipids content and total protein content were carried out. Mineral content was assessed using X-ray fluorescence spectrophotometry in apples with and without peel, revealing significant differences between each variety. Moreover, there were significant differences between height, dry weight content, density, total soluble solids content, firmness, size, colorimetric parameter. Furthermore, significant differences were also observed in Fe, Ca, K, Cl and S content as well as protein and total lipid content. Additionally, Reineta variety emerged as the sweetest variety among the studied varieties and the study also revealed that the mineral content was higher in apples with peel compared to those without peel, highlighting the nutritional importance of apple skin.

Keywords

Apple, lipid content, mineral content, protein content

Introduction

Apples (Malus domestica) are one of the most widely consumed fruits worldwide (FAOSTAT 2020) and the third most produced fruit in the world in 2022 (FAO 2022), valued for their health benefits and essential role in a balanced diet. These fruits are rich in dietary fiber which helps in the maintenance of digestive health (Johnston et al. 2019), vitamins (such as C and A), essential mineral elements (namely, potassium) (USDA Food Data Central 2021). In fact, the regular consumption of apples has been associated with the decreased risk of developing type 2 diabetes (Muraki et al. 2013). Furthermore, apples are one of the main fruits of temperate regions across the globe (Velasco et al. 2010).

The origins of apple cultivation can be tracked to Central Asia, possibly around the Caspian and Black Seas (Hancock et al. 2008). The primary wild ancestor of all cultivated apples is Malus sieversii (Asian wild apple) and other wild species (including M. sylvestris and M. pumila), which are still growing today. Nowadays, apple cultivation is widespread, including Portugal, where the fruit industry holds a notable position in the agricultural sector (INE 2021).

The quality of apples is defined by physical, biochemical, and organoleptic characteristics (Hoehn et al. 2003; Abbott et al. 2004), being texture and taste the most important parameters for consumers. Quality assessment and classification of food products as well as evaluation of taste attributes is necessary in modern markets for buyers

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and producers alike. The chemical composition and quality of apple fruit depends on several internal and external factors. Moreover, variety holds the greatest importance regarding the internal factors (Miljković 2017). External characteristics such as size, shape, absence of defects and color, impact consumer purchasing decisions (Musacchi and Serra 2018). Over the years, research has focused on understanding and improving apple quality, recognizing that consumer preference and acceptance depend on multiple attributes including color, texture and nutritional content (Yahia 2018). Organoleptic characteristics, such as harmony is crucial for taste, being directly influenced by chemical composition, particularly soluble dry matter content (Fonteles and Rodrigues 2018). Apples are constituted by more than 84% water containing minerals such as K, Mg, Ca and Na and trace elements such as Zn, Mn, Cu, Fe, B, F, Se, and Mo (Feliciano et al. 2010). Therefore, the assessment of apple quality and nutrition content has become an important area of study in horticultural research. In this context, this study aims to evaluate the physical and chemical properties of seven different varieties of apples commercialized in Portugal: Jonagold, Reineta, Granny, Pink Lady, Gala, Fuji and Golden, and also to enhance the understanding of apple characterization within the Portuguese fruit industry, providing valuable insights for producers and consumers

Materials and methods

Experimental design

Seven apple varieties (Jonagold, Pink Lady, Fuji, Golden, Reineta, Gala and Granny) were sourced from local supermarket and subjected to different quality analysis at Agro-Industrial Laboratory at Nova School of Science and Technology, Portugal. For each variety, 12 apples were randomly selected. The experiment began on March 7 and lasted until early May of 2022.

Heigh, diameter, and dry weight content

Height and diameter were measured considering four randomly selected apples per variety (n = 4). The dry weight content was determined by the gravimetric method considering four randomized apples of each variety (n = 4), being the dry weight content calculated as the percentage difference between the initial weight and the final dry weight (at 60 °C until constant weight).

Total soluble solids content and fruit density

Total soluble solids were measured in the juice of four randomized apples of each variety (n = 4) using an Atago digital refractometer (DR-A1, ATAGO Co. Ltd., Japan) according to Lommen et al. (2000). The results were expressed as °Brix, representing the percentage of soluble solids per 100 g of product. Density determination was performed using WTW – Conductivity portable meter ProfiLine Cond 3110 device, in quadruplicate (n = 4) for each variety, following Lim et al. (2017).

Colorimetric parameters

Colorimetric parameters were assessed in both pulp and skin of four randomized apples per variety (n = 4) using a fixed wavelength through CieLab system. The different parameters (L, a*, b*, Chroma and Hue) were obtained with a Minolta CR300 colorimeter (Minolta Corp., Ramsey, NJ, USA) coupled to a sample vessel (CR-A504) according to Pessoa et al. (2021). The L parameter is a measure of lightness and varies from 0 (black) to 100 (white); value of a* varies from -100 (green) to +100 (red); value of b* varies from -100 (blue) up to +100 (yellow); value of C (Chroma) represents the relationship between the values of the parameters a* and b*, where the real color of analyzed object is obtained and Hue is the angle formed between a* and b*, indicating the saturation of the object's color.

Firmness and size

Flesh firmness was tested using a Bellevue type penetrometer with a diameter of 0.5 cm (expressed in kilograms) following Barreiro et al. (2001). The penetrometer was also used to measure the size of the apple samples.

Mineral content

The content of micro and macro elements in the different apple varieties were carried out in quadruplicate (n = 4) in samples with and without peel, using X-ray spectrophotometry (model XL3t 950 He GOLDD+) under helium atmosphere, as described in Reboredo et al. (2018). Samples were previously dried (until constant weight at 60 °C) and ground.

Protein content

Total protein content was quantified following Marques et al. (2020) with Kjeldahl method. For each apple variety, four replicates (n = 4) of 1 g each were analyzed. The samples were subsequently placed in glass tubes and the catalyst mixture and 13 ml of sulphide acid was added. The tubes were subjected to a digestion process at 420 °C for 90 minutes and after this process, the tubes were cooled for 30 minutes, and 75 ml of water was added. The distillation of the samples was carried out with 50 mL of NaOH for an erlenmeyer flask with two drops of Toshiro indicator and 30 ml of boric acid. After the distillation, the titration was carried out and protein content was calculated.

Total lipid content

Two grams of homogenized dried sample of each variety (n = 4) were placed in the precipitation glasses and loaded into an automated Soxtherm fat extraction system (VELP). Briefly, 100 mL of petroleum ether was added to the different precipitation glasses. In the automated extraction program, the process starts with the samples being boiling with petroleum ether for 90 min, rinsing stage of 60 min, a recovery stage of 30 min, and after that the samples are dried at 105 °C for the evaporation/drying stage during 60 min. After that, the precipitation glass was weighed, and percent crude fat was calculated.

Statistical analysis

Statistical analysis was performed using IBM SPSS software. One-way ANOVA was employed to assess the differences between varieties foreach parameter analyzed, followed by Tukey's post-hoc test for mean comparison. A 95% confidence level was adopted for all the tests carried out.

Results

Considering the seven apple varieties examined in this study, height, diameter, dry weight content, density and total soluble solids were quantified and analyzed (Table 1). Significant differences were observed among the varieties for height, dry weight content, density, and total soluble sugars, while diameter values were similar across all varieties. Fuji exhibited the greatest average height, whereas Reineta had the smallest height. The diameter of the seven apple varieties recorded similar values ranging from 70.25 to 75.75 mm, showing no significant differences. Reineta variety presented the highest dry weight content, while Gold had the lowest, Similarly, Golden variety showed the lowest density compared to the reaming varieties studied, whereas Gala variety exhibited the highest density. The dry weight content (expressed as percentage) in the seven varieties varied between 13.66% to 18.95%, in which the lowest content was obtained from Golden variety and the highest in Reineta variety. The total soluble solids varied between 13.13 °Brix (Golden) to 17.58 °Brix (Reineta).

The colorimetric parameters of the seven apple varieties were evaluated using the CieLab color space system in apples with and without peel (Table 2). Significant differences were observed in colorimetric parameters both between samples with and without peel. Considering L parameter, Golden variety in both sample preparation (with and without peel) showed the highest value. Considering apples without peel, Fuji variety showed the lowest value and the highest values in b* and Chroma parameters. In contrast, Pink Lady showed the lowest b* and Chroma values, Gala had the highest a* value and the lowest Hue. Granny variety presented the lowest value in both

Table 1. Mean values of height, diameter, dry weight content, density, and total soluble solids ± S.E. (n = 4) physical properties of seven apple varieties: Jonagold, Pink Lady, Fuji, Golden, Reineta, Gala and Granny.

Varieties	Height (mm)	Diameter (mm)	Dry weight content (%)	Density (kg/m³)	Total soluble solids (°Brix)
Jonagold	70.25 ± 0.960ab	74.75 ± 0.740a	17.25 ± 0.116ab	1088 ± 42.45ab	15.13 ± 0.393b
Pink Lady	69.75 ± 1.556ab	75.25 ± 0.960a	14.67 ± 0.383ab	1024 ± 15.09ab	13.93 ± 0.222bc
Fuji	67.75 ± 1.293ab	72.50 ± 1.031a	17.79 ± 0.836ab	1096 ± 6.47ab	15.33 ± 0.129b
Golden	76.50 ± 1.820a	71.50 ± 0.829a	13.66 ± 0.967b	1007 ± 19.24b	13.13 ± 0.315cd
Reineta	64.00 ± 1.458b	73.25 ± 1.431a	18.95 ± 0.579a	1044 ± 12.90ab	17.58 ± 0.167a
Gala	67.50 ± 1.601ab	70.25 ± 1.516a	17.29 ± 1.305ab	1180 ± 29.47a	14.45 ± 0.238bc
Granny	71.25 ± 1.139ab	75.75 ± 0.960a	16.00 ± 1.710ab	1075 ± 53.07ab	12.08 ± 0.349d

Different letters (a,b) indicate significant differences between varieties for each parameter (statistical analysis using the single factor ANOVA test, $P \leq 0.05$).

Table 2. Mean values ± (S.E.) (n = 4) of colorimetric parameters of seven apple varieties: Jonagold, Pink lady, Fuji, Golden, Reineta, Gala and Granny.

	Varieties	L	a*	b*	Chroma	Hue
Without peel	Jonagold	80.67 ± 0.64a	4.863 ± 0.22ab	24.43 ± 0.32ab	24.92 ± 0.36abc	101.2 ± 0.35b
	Pink Lady	80.43 ± 0.42ab	-3.571 ± 0.16a	18.12 ± 0.80b	18.47 ± 0.81c	101.2 ± 0.23b
	Fuji	69.82 ± 4.04b	-5.931 ± 0.74ab	27.07 ± 1.80 a	27.741 ± 1.86a	102.3 ± 1.20b
	Golden	81.37 ± 1.02 a	-4.829 ± 0.68ab	23.21 ± 0.68ab	23.718 ± 0.71abc	101.74 ± 1.20b
	Reineta	76.58 ± 0.85ab	5.611 ± 0.85ab	25.81 ± 1.42a	26.209 ± 1.56ab	102.1 ± 1.24b
	Gala	75.23 ± 2.73 ab	-3.339 ± 0.27a	22.03 ± 1.79ab	22.283 ± 1.80abc	98.69 ± 0.59b
	Granny	75.91 ± 1.72 ab	-6.664 ± 0.63b	18.77 ± 1.30b	19.92 ± 1.43bc	109.4 ± 1.09a
With peel	Jonagold	52.15 ± 2.31bc	19.84 ± 2.40b	32.07 ± 1.56c	18.473 ± 0.81c	58.27 ± 4.23d
	Pink Lady	56.73 ± 3.63bc	20.89 ± 4.63b	33.29 ± 2.13c	22.725 ± 0.63b	58.37 ± 6.53d
	Fuji	62.89 ± 1.52ab	1.143 ± 3.14c	35.67 ± 0.97bc	23.718 ± 0.71b	87.79 ± 5.17c
	Golden	68.23 ± 0.91a	-15.42 ± 0.59d	46.49 ± 0.59a	26.209 ± 1.56 a	108.4 ± 0.48ab
	Reineta	52.96 ± 1.38bc	-0.920 ± 0.68c	32.64 ± 1.14c	22.283 ± 1.78b	91.50 ± 1.20bc
	Gala	48.65 ± 1.19c	37.72 ± 0.15a	27.21 ± 2.04d	19.920 ± 1.43c	35.60 ± 2.08e
	Granny	62.15 ± 2.59ab	-17.73 ± 0.42d	40.90 ± 1.52b	25.576 ± 1.21ab	113.6 ± 4.75a

Different letters (a,b) indicate significant differences between varieties for each parameter (statistical analysis using the single factor ANOVA test, $P \leq 0.05$).

a* and in Hue parameters. For apples with peel, Jonagold showed the lowest Chroma value, followed by Gala variety. Indeed, Golden variety showed the highest L, b* and Chroma values and the lowest a* parameter. Moreover, Gala displayed the lowest in L, b* and Hue values but had the highest a* parameter, whereas Granny variety showed the lowest a* value and the highest Hue.

Firmness and size measurements of the seven apple varieties revealed significant differences among varieties (Table 3). Reineta variety exhibited both the strongest firmness and largest size, significantly differing from other varieties such as Jonagold. Conversely, Gala was identified as the smallest variety among the seven studied.

Table 3. Mean values ± (S.E.) (n = 4) of firmness and size of seven apple varieties: Jonagold, Pink Lady, Fuji, Golden, Reineta, Gala and Granny.

Varieties	Firmness (g/cm³)	Size (mm)
Jonagold	5009 ± 622d	189 ± 1.03ab
Pink Lady	7589 ± 132abc	187 ± 1.06ab
Fuji	6225 ± 174bcd	184 ± 0.94bc
Golden	5738 ± 125cd	188 ± 0.54ab
Reineta	8151 ± 628a	191 ± 1.29a
Gala	6788 ± 218abcd	182 ± 0.41c
Granny	7991 ± 144ab	188 ± 0.41ab

Different letters (a,b) indicate significant differences between varieties for each parameter (statistical analysis using the single factor ANOVA test, $P \leq 0.05$).

Mineral content analysis was conducted in order to determine the concentration of essential mineral elements, specially, Fe, Ca, K, Cl and S in the seven apple varieties studied with peel (Fig. 1) and without peel (Fig. 2). The analysis revealed significant differences in Fe, Ca, K, Cl and S content among apple varieties with peel (Fig. 1), indicating the diversity in nutritional profiles. As such, Fuji variety presented as the one with the lowest Fe, Ca, K and Cl content compared to the reaming varieties. Moreover, Golden showed significantly higher contents of Fe and Cl, Granny variety of Ca and S and Gala of K. Among all mineral elements analyzed in apples with peel, Ca was consistently found in lower concentrations.

For apples without peel (Fig. 2), significant differences were also observed for Fe, Ca, K and Cl (except S). Gala variety demonstrated the lowest Fe and Cl contents, but the highest K concentration, while Pink lady showed significantly higher Fe, Ca and Cl contents compared to the other varieties studied. Reineta and Golden presented the lowest Ca and K content, respectively. Similar to apples with peel, Ca remained the least abundant mineral element among the mineral elements analyzed.

Protein and total lipid content analyses showed significant differences among the seven different apple varieties (Table 4). Regarding protein results, Granny and Golden varieties presented the highest content, while Fuji variety had the lowest protein content among the seven varieties. For lipid content, Pink Lady showed the highest lipid content, whereas Golden variety had the lowest lipid content.

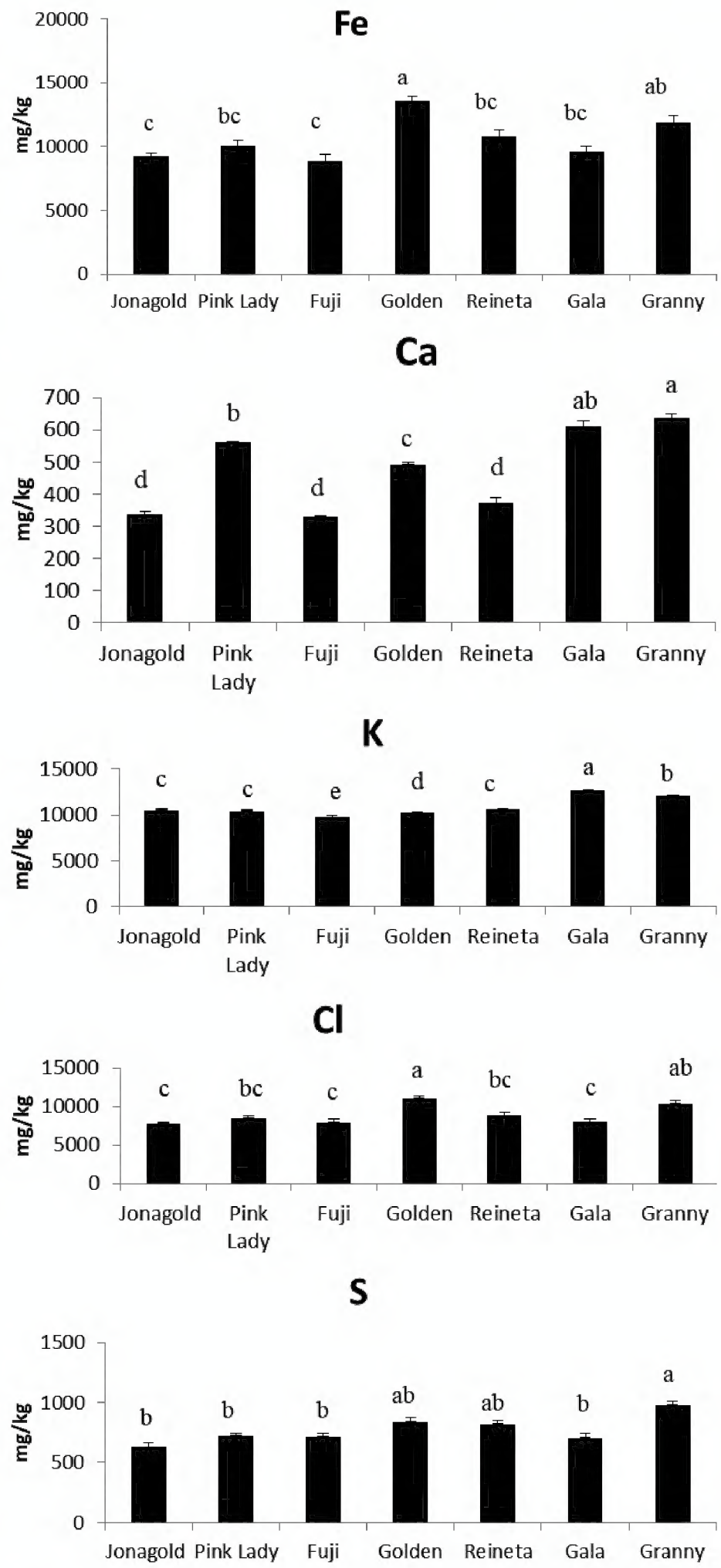

Figure 1. Mean values ± S.E. (n = 4) of Fe, Ca, K, Cl and S in seven apple varieties with peel: Jonagold, Pink Lady, Fuji, Golden, Reineta, Gala and Granny. Different letters (a,b) indicate significant differences between varieties for each parameter (statistical analysis using the single factor ANOVA test, $P \leq 0.05$).

Discussion

The present study provided insights regarding apple quality and highlighted the importance of variety-specific characteristics in determining apple quality and nutritional value.

A minimum and maximum size is recommended for all types of fruit, including apples. These standards consider

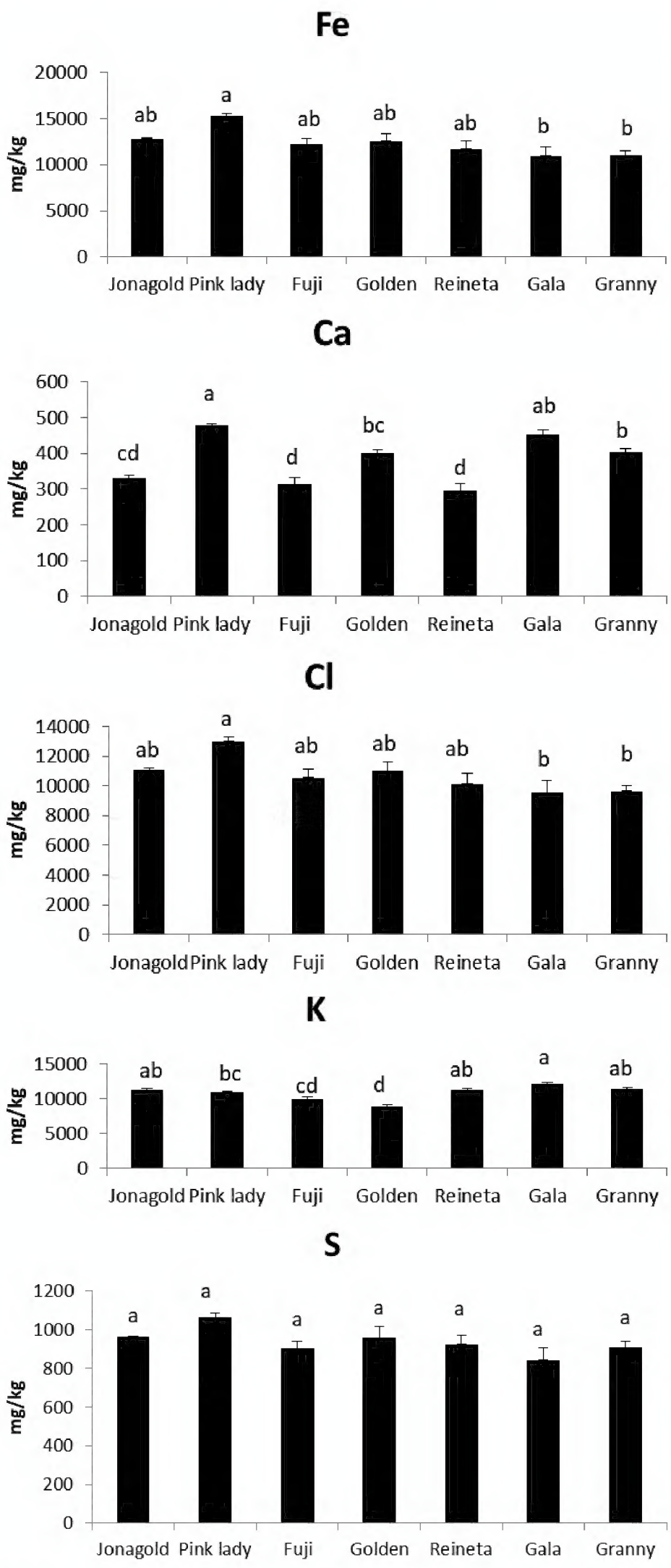

Figure 2. Mean values ± S.E. (n = 4) of Fe, Ca, K, Cl and S in seven apple varieties without peel: Jonagold, Pink Lady, Fuji, Golden, Reineta, Gala and Granny. Different letters (a,b) indicate significant differences between varieties for each parameter (statistical analysis using the single factor ANOVA test, $P \leq 0.05$).

varietal characteristics, alongside factors. Typically, the size of apples required by large distributors is usually a minimum of 60 or 65 mm in diameter for early varieties, and 70 or 75 mm for medium and late varieties, with a maximum allowable diameter of 80 or 85, rarely 90 mm (Mešić et al. 2019). According to our results (Table 1), Golden variety

Table 4. Mean values ± S.E. (n = 4) of protein and total lipid content of seven apple varieties: Jonagold, Pink Lady, Fuji, Golden, Reineta, Gala and Granny.

Varieties	Protein content (%)	Total lipid content (%)
Jonagold	0.929 ± 0.001f	0.733 ± 0.085b
Pink Lady	1.272 ± 0.040e	0.814 ± 0.086a
Fuji	0.738 ± 0.006g	0.431 ± 0.024d
Golden	2.136 ± 0.027b	0.348 ± 0.070e
Reineta	1.507 ± 0.100d	0.581 ± 0.131c
Gala	1.834 ± 0.061c	0.547 ± 0.081c
Granny	2.224 ± 0.060a	0.550 ± 0.040c

Different letters (a,b) indicate significant differences between varieties for each parameter (statistical analysis using the single factor ANOVA test, $P \leq 0.05$).

achieved the largest height with a total of 76.5 mm, which following to previously described research is a medium and accepted height. Additionally, considering the characteristics of Golden variety, the height of 71 mm reported in Franquin et al. (2005), shows a small difference compared to our data (Table 1). Nevertheless, the lowest results for height were obtained with Fuji and Reineta varieties (Table 1), with about 67 mm, which according to the results of other research on this parameter, the data obtained for Fuji (Gonzalez et al. 2019) and Reineta (Batelja-Lodeta 2019) were similar to our data.

Data obtained for Reineta and Golden varieties in diameter (Table 1), were similar to the ones obtained in a study carried out by Verde et al. (2022). Notably, Reineta exhibited the highest dry weight content (Table 1), which is according to data obtained in another study carried out with the same variety (Fuente et al. 2013). Furthermore, Halagarda and Suvala (2018) states that the lower the density of apple, the more consumers prefer it. Gala presented the highest density among the seven varieties studied (1180 kg/m^3), which differs from the density obtained in Váquiro et al. (2012) research (varying between 1219.6 to 1232.7 kg/m^3).

The differences observed in colorimetric parameters between samples with and without peel (Table2) show the importance of visual appearance in apple quality assessment. These color variations are not only aesthetic but often indicate differences in phytochemical composition, particularly in anthocyanins, flavonoids, chlorophylls, and carotenoids (Kobašček 2016). Also, light is a factor that shows redness of the apple skin (Lancaster et. al 2008). As such, considering L parameter, our data in samples of apples with skin showed lower values compared to samples tested without peel. In a study carried out by Jakopić et al. (2011) Golden apple peel color results are lower compared to our data for the same variety with peel and also lower than samples tested without peel. The color of Jonagold variety without peel showed higher illuminance compared to that examined in the study carried out by Kashif et al. (2013). Moreover, according to Table 2, peel color of Gala variety is red, and significantly similar results are shown on a research carried out with the same cultivar by Peruzzo-Ferrareze (2017). For instance, both Golden and Granny varieties, the peel color tended towards to

green and are similar to what is reported for Gala variety in Henríquez et al. (2012) study.

The colorimetric parameters obtained for the inside of apples of Pink Lady and Gala varieties presented as slightly greener than the data obtained by Henriquez et al. (2010) research. In the same study, the b * parameter values for Gala sampled with peel had higher values compared to the ones obtained in our study (Table 2). Also, the values obtained for b* parameter for Granny, Fuji, and Pink Lady without peel in Henriquez et al. (2010) research are lower relatively to the values obtained in our study (Table 2). Considering our data in Chroma parameter again shows higher values in samples with peel relatively to the ones obtained by Henriquez et al. (2010) study, while the results of samples without peel shows no differences. The highest values of Hue parameter were achieved by the Granny variety with peel, showing no differences compared to Henriquez et al. (2010) data. Furthermore, the colorimetric parameters obtained for Gala variety with peel presented the lowest values and differs from Łysiak (2012) research. The Hue parameter showed higher values compared to other study carried out for Granny variety without peel (Jemrić 2012). In this context, these color variations are fewer and indicate the variations regarding the origin of apples.

To optimize consumer satisfaction Echeverría et al. (2002) recommended TSS values between 13.5 and 15.5 °Brix. In our study (Table 3), Reineta variety presented a TSS content of 17.58%, being a higher content compared to the one reported by Reig et al. (2015) (15.5 °Brix). Additionally, the minimum value recorded in our study has obtained with Granny variety (12.08 °Brix) which is lower than the value of 12.5 reported by Board and Woods (1983). Also, the values of TSS obtained for Gala variety are similar to the ones obtained for the same variety in another study carried out with Portuguese apples (Mota et al. 2022). Regarding firmness (Table 3) our data are similar to the one obtained for Gala variety in Mota et al. (2022) research.

Macro and micro elements content were analyzed in apples with (Fig. 1) and without peel (Fig. 2) of the seven varieties. Moreover, there results obtained provided an overview of Fe, Ca, K, Cl and S content, highlighting the diversity in the mineral profile among the varieties studied. As such, the mineral composition of apples can vary depending on the variety, region of production and horticultural practice (Róth et al. 2007). In fact, apples are considered to be a rich source of nutritional elements, having a great impact on human nutrition but also on the quality of fruits (Agnolet et al. 2017). Macronutrients play an important role in achieving high, stable yields and high-quality products. Plants require them in larger quantities (Vavetić 2016). For instance, Ca is a macroelement and apples need it in large quantities for physiological processes of all tissues and organ building (Krpina et al. 2009). The most common macronutrient is K, which is important for heart function, the body's immune response and is necessary for functioning nervous system (Hui 2016). The content of macroelements in our study showed to be higher in apples with peel compared to apples without peel, which was already previously reported (Sachini et al. 2020). Considering the microelements (also called astrace elements) are, considering-needed in smaller amounts than macronutrients (Karlić 2015). Regarding Fe, it is involved in the production of chlorophyll, and its deficiency is visible on young leaves (presenting a yellow color), especially easily noticeable on calcareous soils. Iron is also building a component of many enzymes involved in energy transfer, nitrate reduction, nitrogen fixation and lignin formation. Chlorine also indirectly affects plant growth by regulating activity stoma and water loss (Gluhić 2013).

Compared to another research carried out by Feliciano et al. (2010), our data shows a higher protein content (Table 4), probably due to cultivation conditions. However, according to INSA (2024) the average protein content is 1.3%, as such, Jonagold, Fuji and Pink Lady presented a lower protein content and Granny, Golden, Gala and Reineta a higher one, indicating that protein content is variety dependent. Regarding the total lipid content (Table 4), there was a significantly higher content in Pink Lady regarding the remaining varieties, however, the results obtained were lower than the reported by Sato et al. (2010).

In this context, this comprehensive characterization of seven apple varieties reveals significant diversity in physical and chemical properties, being necessary future research which could explore how these varietal differences can be associated with potential health benefits and impact consumer choice, industrial processing and nutritional recommendations.

Conclusion

The aim of this research was to examine the influence of the physical and chemical properties of seven varieties of apples: Jonagold, Pink Lady, Reineta, Golden, Granny, Fuji and Gala, both with and without peel, to assess their differences. The research revealed significant differences between each parameter analysed (except for diameter) among varieties, indicating that each variety has different and unique dietary profiles and potential applications considering the nutritional requirements. Moreover, Reineta variety presented as the sweetest variety, with higher TSS. Additionally, mineral content was reported to be higher in apples with peel compared to those samples without peel, highlighting the nutritional importance of apple skin.

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